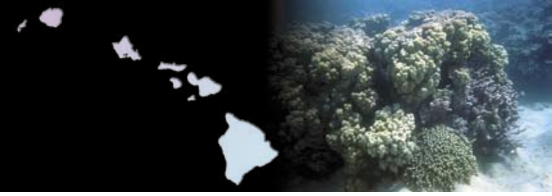
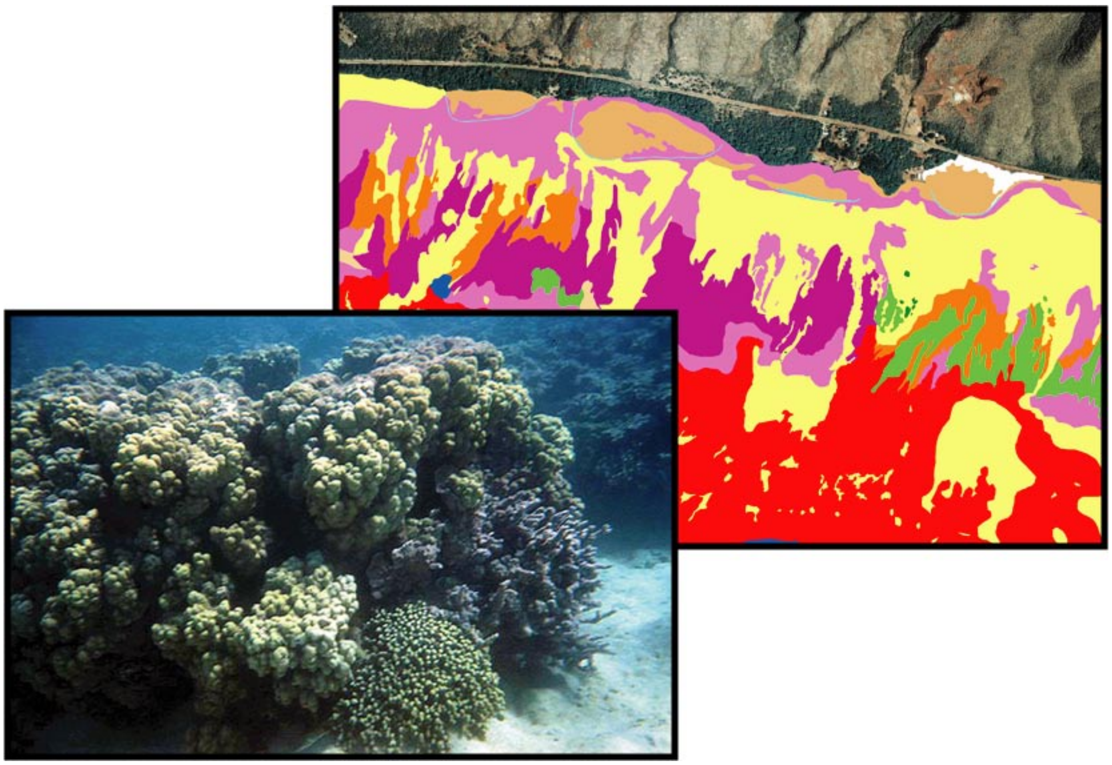


Moloka'i Benthic Habitat Mapping

By Susan A. Cochran-Marquez



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U.S. Department of the Interior
U.S. Geological Survey

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Moloka'i Benthic Habitat Mapping

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Introduction

In order to provide evidence of change in any ecosystem, one must first have a starting point, or "baseline" inventory of resources. Thematic maps providing this baseline inventory are an important tool in assessing change in coral reef ecosystems, allowing scientists to spatially document the location of corals, percentage of coral cover, and relative overall health of the system. In the last decade, scientists and managers have recognized the lack of thematic maps for coral reefs worldwide. In 1998, the President of the U.S. issued Executive Order 13089 establishing the U.S. Coral Reef Task Force (CRTF). Comprised of several Federal agencies, including the U.S. Geological Survey, the primary duty of the CRTF is mapping and monitoring of coral reefs in the U.S. and U.S. Trust Territories.

Moloka'i is one of the main eight Hawaiian Islands (Figure 1). The south shore of Moloka'i is home to the most continuous fringing coral reef in U.S. waters. Prior to 1998, the University of Hawai'i Marine Options Program undertook the only coral reef mapping effort of the south Moloka'i reef for the U.S. Army Corps of Engineers (Manoa Mapworks, 1984). Qualitative field data were collected over a two-week period using SCUBA and snorkel, and maps were plotted using 1:6K and 1:24K black and white aerial photography from 1975 as a base layer. These maps provide a useful background to the reef ecosystem, however the aerial photographs were not georectified, and thus no true quantitative measurements of scale and distribution can be made from the 1975 imagery.

In 1999, in response to the mandate set forth by Executive Order 13089, The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) implemented a program to provide digital maps of our nation's coral reefs for use in a geographic information system (GIS). The south Moloka'i reef was mapped using orthorectified aerial photography, hyperspectral remotely sensed images, and quantitative field observations (Coyne et al., 2003). The classification scheme used to produce these maps documented 9 out of a possible 23 distinct benthic habitat types on the south Moloka'i reef, and 10 out of a possible 14 morphological reef zones. However, under the restrictions of a 1 acre minimum mapping unit (MMU) at a 1:6K scale, many smaller details of the reef system were overlooked.

One of the strategic goals of the U.S. Geological Survey is to assist land-use managers by establishing the geologic framework for ecosystem structure and function. Here we provide a detailed high-resolution map and habitat characterization of a critical coral reef in Hawai'i that is of concern to resource managers and the public. The threats to the reef off the south shore of Moloka'i, including excessive sedimentation and pollution concerns, were a few of the major influences for selecting this site to develop procedures for producing these maps. Without the NOAA 1 acre MMU and 1:6K scale restrictions, the USGS is in a position to provide higher-resolution benthic habitat maps of the Moloka'i reef. These maps can be used as stand-alone or in a GIS, and provide useful information to scientists, managers and the general public.

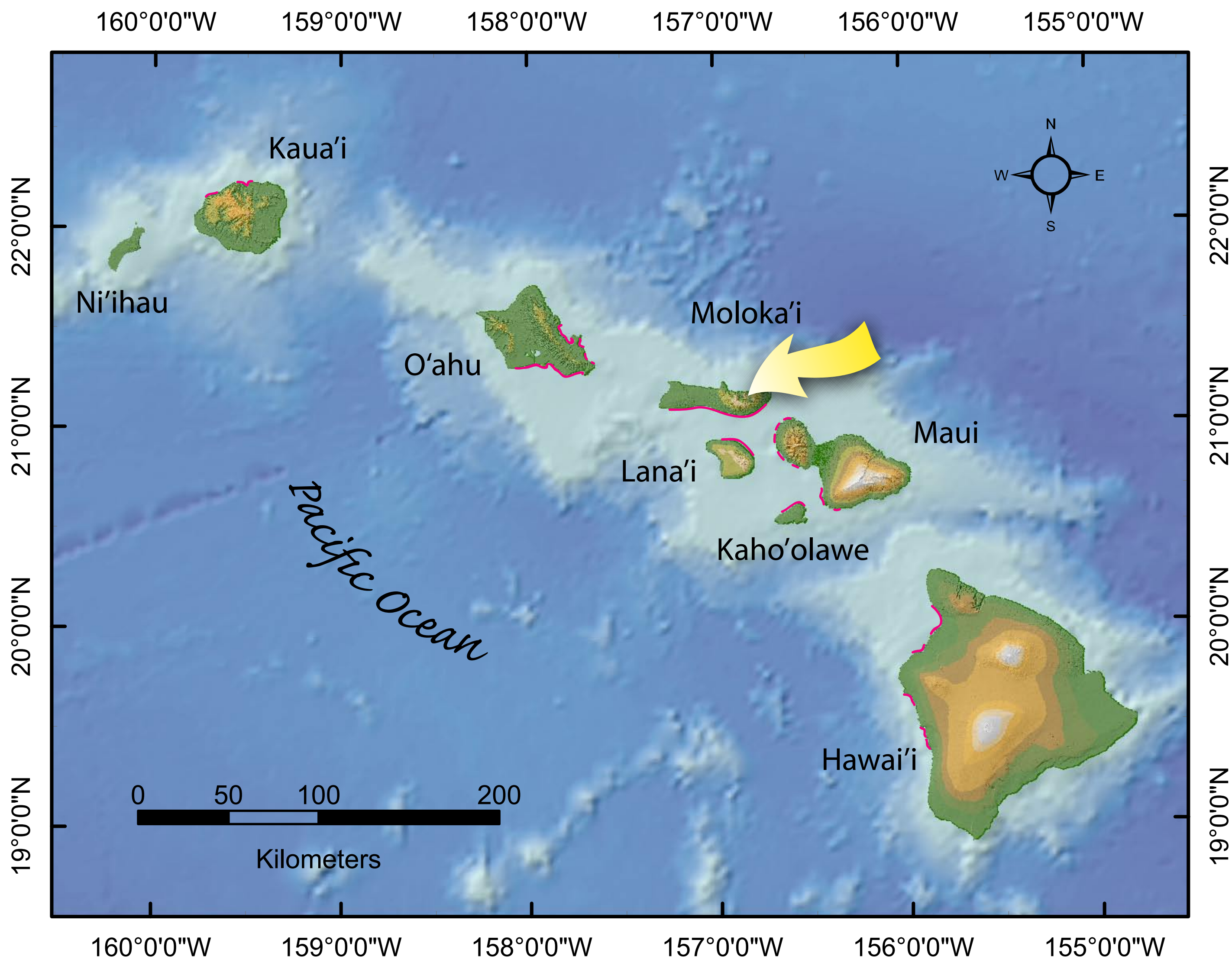

Figure 1. *Map of* ***the main eight Hawaiian Islands. Some areas of known coral reef growth are shown in pink. The arrow denotes the location of the island of Moloka'i.***

Methods

The USGS Moloka'i Benthic Habitat Classification Map was created from visual interpretation of aerial photography and SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) bathymetric data. In addition to the remotely sensed imagery, we utilized *in situ* knowledge from field data collected over a period of four years (1999 – 2003). These field data were collected using towed instruments, SCUBA, snorkel, and on foot, and include underwater photographs, video, and visual observations recorded in waterproof notebooks. Mapping was accomplished using a Geographic Information System (GIS) and a statistical analysis of accuracy was performed. The flowchart in Figure 2 illustrates the complete methodology.

Background Data - Base Layers

Aerial photography and SHOALS bathymetry data were used as the base layers for the visual interpretation of south Moloka'i reef benthic habitats. Aerial photographs at a scale of 1:35K, from Hale O Lono on the southwest end of the island to Puko'o in the southeast, were collected in 1993 by NOAA. These images were post-processed and mosaicked by the USGS, resulting in orthorectified digital images with a 1 meter per pixel resolution. Aerial photography at a scale of 1:24K collected by NOAA in 2000 was used for the extreme eastern portion of the south Moloka'i reef from Puko'o to Kumimi. These images were post-processed and mosaicked by a NOAA contractor, resulting in an additional orthorectified digital image with a 1 meter per pixel resolution. For further details on NOAA aerial photography for Moloka'i see http://biogeo.nos.noaa.gov/.

Two SHOALS bathymetry datasets were collected in 1999 and 2000 along the south shore of Moloka'i by the U.S. Army Corps of Engineers (USACE), and post-processed and mosaicked by the USGS. Each of these datasets has a 4 meter per pixel resolution, however, the slight offset and overlap of the two datasets results in an overall image resolution of 2 meters per pixel. For further details regarding SHOALS data see http://shoals.sam.usace.army.mil. The maximum depth one can determine underwater features in the SHOALS bathymetric data is 35 m (120 ft), as compared to only 10-15 m (30-45 ft) in the aerial photography.

Background Data - Other Data Used

Several other data sources were helpful in the visual interpretation of the digital base layers. *In situ* knowledge of the south Moloka'i reef was gained over a period of four years (1999 – 2003), by walking and snorkeling the shallow reef flat areas, and using SCUBA and towed instruments in the deeper offshore areas of the reef. This knowledge comes from a collection of underwater photographs, underwater video, and visual observations.

Reef Flat Transects

More than 40 shore-normal survey transects were completed by walking and snorkeling the shallow south Moloka'i reef flat. Approximately every ten meters along a transect line, the benthic habitat was documented in a waterproof notebook, occasionally a photograph was taken, and the latitude and longitude coordinates were marked using a hand-held GPS. Additional data collected during these reef flat transects include sediment thickness and sediment samples to be used in other USGS studies of the effects of sedimentation on the reef.

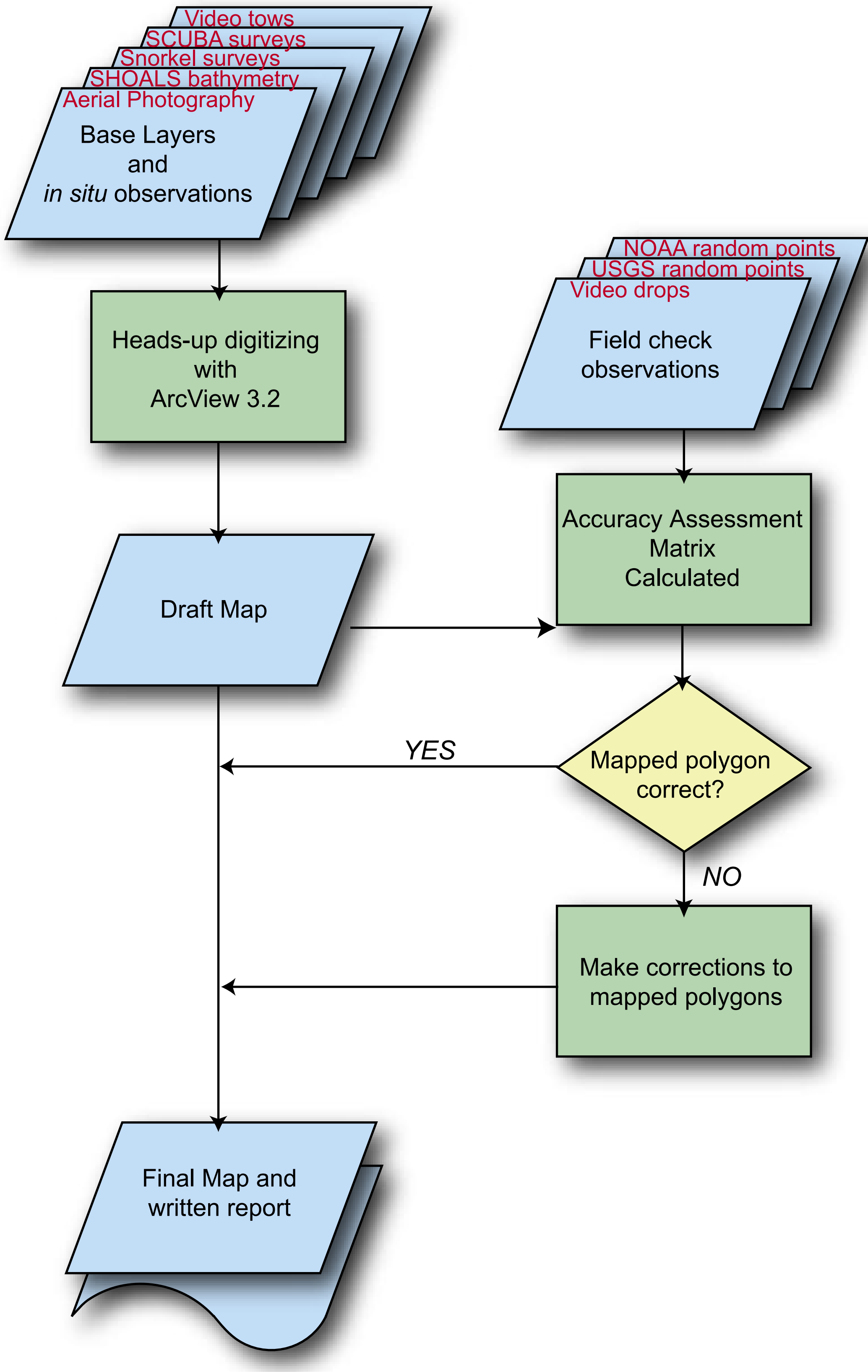

Figure 2. *Flowchart illustrating methodology used to create habitat map. See text for complete description.*

SCUBA Surveys

Underwater video footage was collected on the fore reef along 15 shore-normal transects using a hand-held digital video camera in an underwater housing by divers on SCUBA. The latitude and longitude coordinates were collected with a hand-held GPS at the beginning of each transect. Divers collected video while traveling along a pre-determined direction, and additional coordinates were taken at the end of the transect.

Deep-Water Video Tows

In water deeper than –27 m (-90 ft), underwater video footage was collected by towing a video camera along 30 transects, both shore-normal and shore-parallel. The camera system was connected to an onboard data logger and GPS receiver, which recorded the precise coordinates of the boat on the digital video.

Other Observations

Other data in the knowledge bank include georeferenced observations of bottom type and coverage as seen from the surface with a mask or viewbox. A total of 22 of these “head-in-the-water” observations were collected every few kilometers along the 10 m (33 ft) bathymetric contour from Hale O Lono to Kamalo. In addition, numerous hours of hand-held underwater video and still photographs were collected by scientists on SCUBA and snorkel throughout the course of the study. Although these data are not georeferenced to a specific latitude and longitude, the approximate location of the dives was known, and thus they provide a general idea of the bottom coverage types in those areas.

GIS Beginnings and Heads-up Digitizing

The benthic habitat maps were created using ESRI’s ArcViewGIS v.3.2 software with a Habitat Digitizing extension created by NOAA (to download the extension see http://biogeo.nos.noaa.gov/products/hawaii_cd/htm/digitize.htm). The Habitat Digitizing extension allows users to delineate habitat areas using “heads-up digitizing” and assigns attributes to the habitat polygons based on a pre-determined classification scheme using a point-and-click menu system.

The classification scheme used was based on a scheme established by NOAA’s biogeography program in 2002, and subsequently revised in 2004. Developed with input from coral reef scientists, managers, local experts, and others, the hierarchal scheme allows users to expand or collapse the level of thematic detail as necessary. It was decided to use NOAA’s scheme as a starting point to provide some continuity to the coral reef scientific community. However, modifications were made to the original scheme in order to better reflect the benthic habitats, geologic substrates and historical features (such as fishponds) found on Moloka’i.

The modified classification scheme uses four basic attributes to describe each polygon on the benthic habitat map: 1) the dominant geomorphologic structure or underlying substrate; 2) the major biologic cover found on the substrate; 3) the percentage of major biological cover and, 4) the geographic zone indicating the location of the habitat (Figure 3). Note that 0% to <10% is not considered a category of percentage for any biological cover, as it is the equivalent of 90% tp 100% Uncolonized. Each combination of a geomorphologic structure with an overlying biologic cover may be described as a separate habitat. A zone describes the cross-shelf location of a habitat and is common to current coral reef literature (Figure 4).

More than 4200 polygons, covering over 120 km^2, were digitized by interpreting features seen in both the aerial photographs and SHOALS bathymetry layers, with additional input from other known data. A minimum mapping unit (MMU) of 100 m^2 was used, however smaller features were mapped if they carried habitat significance (e.g., an individual coral colony 2 m in diameter located in an otherwise uncolonized area).

1) Geomorphic Structure/Substrate

Hardbottom
- Aggregate Reef
- Spur and Groove Reef
- Aggregate Patch Reef
- Individual Patch Reef
- Pavement
- Pavement with Sand Channels
- Scattered Coral/Rock
- Reef Rubble

Softbottom
- Sand
- Mud

Other
- Artificial (e.g. Wharves)
- Artificial/Historical (e.g. Fishponds)
- Land

Unknown

2) Biological Cover
- Coral
- Coralline Algae
- Emergent Vegetation
- Macroalgae
- Mangrove Trees
- Uncolonized
- Unclassified (Land or Artificial)
- Unknown

3) % Biological Cover
- 10% to <50%
- 50% to <90%
- 90% to 100%

4) Geographic Zonation
- Land
- Shoreline/Intertidal
- Reef Flat
- Reef Crest
- Fore Reef
- Shelf
- Shelf Escarpment
- Channel
- Dredged
- Vertical Wall

Figure 3. *List of structure/substrate, biological cover, % biological cover and geographic zones used in the classification scheme (modified from NOAA National Centers for Coastal Ocean Science, 2005).*

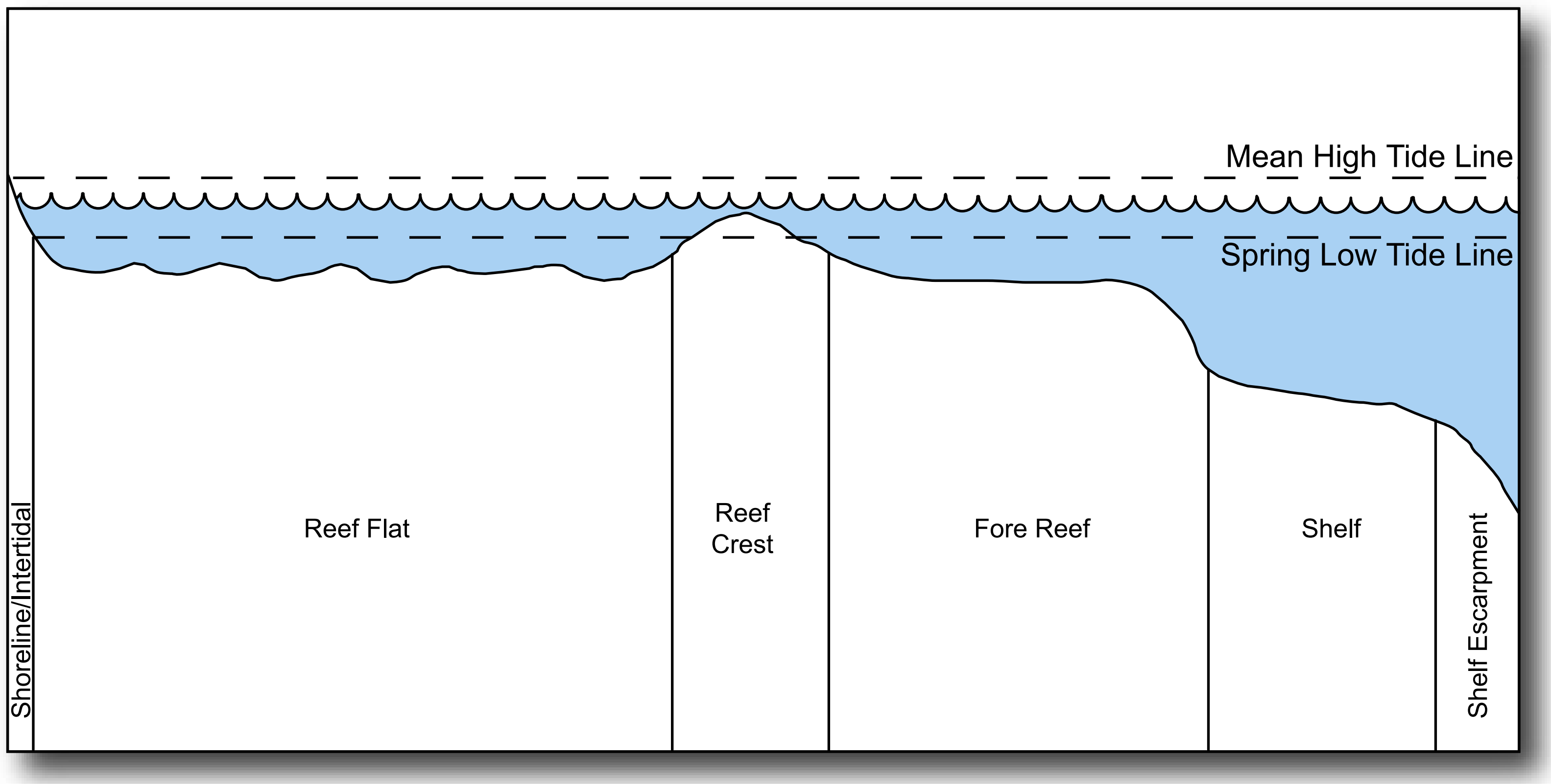

Figure 4. *Schematic diagram showing the generalized cross-shelf coral reef zonation. Not shown are Land, Channel, Dredged or Vertical Wall (modified from Kendall et al., 2005).*

Accuracy Assessment

The validity, or usefulness, of any classification or interpretation may be determined with an accuracy assessment, which compares the interpretation with what is actually found in the field. In this project, the map's overall accuracy and accuracy from both the User and Producer points of view were determined.

Overall accuracy indicates which points on the map are classified correctly according with a field check (Lillesand and Keifer, 1994). Producer accuracy indicates how well the map producer classified the different cover types (i.e., the number of points on the map labeled correctly). User accuracy indicates the probability that a point in a given class is actually represented by that class in the field (i.e., which mapped areas are actually what they say they are).

A combination of field check data was used to measure the accuracy of the benthic habitat maps. Along the forereef, over 500 observations were made by lowering a video camera system vertically in order to collect images of the bottom type. In the nearshore waters of the reef flat nearly 50 randomly generated sample points were checked. In addition, observations made on the reef flat at over 200 randomly generated sample points, plus nearly 100 sampling points, from the NOAA database (http://biogeo.nos.noaa.gov) were used in the accuracy assessment.

Once the accuracy assessment calculations were completed, misinterpreted polygons were corrected, thus increasing the percent accuracy of the final map.

Results

Dominant Structure/Substrate

The South Moloka'i reef was classified into 14 different structures, or substrates, that delineate the reef morphology. Nearly 66 km^2 (54% of the total area mapped) consists of combined reef and hardbottom substrates; softbottom sand and mud comprise just over 52 km^2 (43%), as shown in Figure 5.

A major feature of the South Moloka'i reef is the broad, shallow pavement platform of the reef flat, which extends nearly 1.5 km offshore in the Pala'au and Kaunakakai areas. A mud veneer and ancient fishponds lie close to shore, while sand patches and coral-covered pavement dominate the seaward edge of the reef flat.

Seaward of the reef crest, the fore reef alternates between abundant reef and barren hard pavement**.** The fore reef follows a spur and groove morphology pattern, which is especially pronounced in the west. Aggregate reef growth is predominantly observed in the Pala'au and Kamalo regions. The areas off Kamiloloa and Puko'o, however, are barren "dead zones" of hard pavement with little or no active reef development.

The base of the fore reef is around a depth of 27 m (90 ft), where it transitions into a gently sloping sand-covered plain of the shelf zone. Reef development pinches out near the ends of the island where high wave energy likely limits growth (Storlazzi et al., 2003).

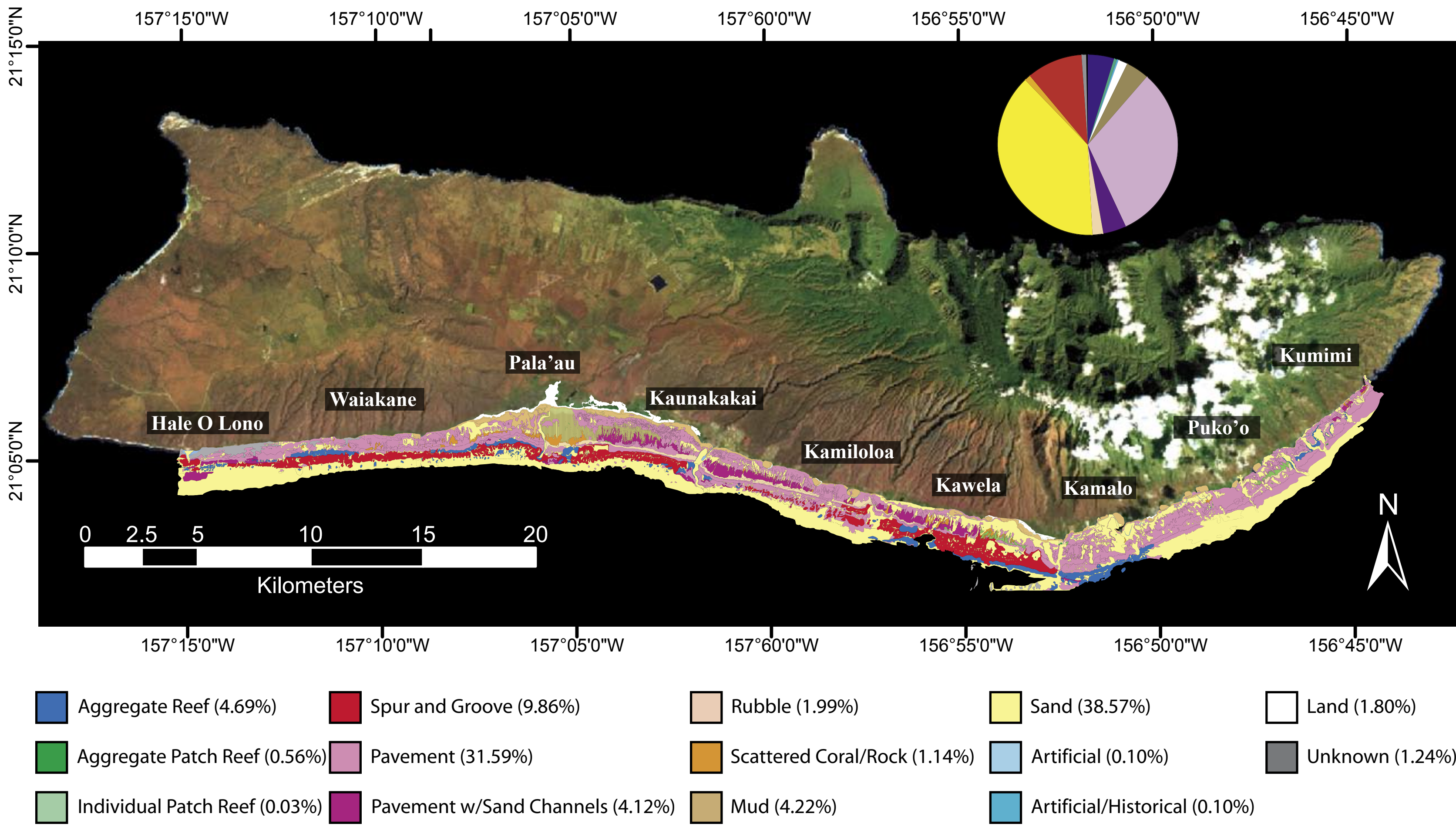

Figure 5. *Landsat satellite image overlaid with the benthic habitat classification map of Moloka'i showing the Dominant Structure/Substrate layer and the percentage of each class.*

Major Biological Cover

The 14 different structures/substrates are covered with 8 different biological habitat classes. Coral covers 51% of the suitable hard substrate on the South Moloka'i reef (over 34 km^2 or 28% of the overall study area), as shown in Figure 6.

Coral cover varies geographically. The highest percentages are found offshore of the Pala'au and Kamalo areas. Studies have shown Pala'au and Kamalo to have the highest coral coverage in the main Hawaiian Islands (Jokiel et al, 2001). Offshore of Kamiloloa and Puko'o are large "dead zones" where the hard pavement is barren or covered with macroalgae (e.g. *Halimeda sp*.).

The coral-covered pavement at the seaward edge of the reef flat is dominated by *Porites lobata* colonies. These shallow colonies appear as knobby flat-topped mesas, with live tissue on the sides of the coral mounds. Surface exposure, wave influences, and/or present sea-level prevent vertical growth of these coral mounds. These flat-topped coral mounds can be exposed at low tides, making it difficult for live coral tissue to grow. The irregular surface of the knobby mounds sometimes has macroalgae or coralline algae growing on it, and may contain sediment in the depressions, or "pukas".

Aggregate reefs and spur and groove formations on the fore reef are dominated mostly by *Porites sp*. and *Montipora sp.* Large patches of the macroalgae, *Halimeda sp*. may be found in the sand at the base of the fore reef around 27 m (85 ft) depth. These calcareous algae are likely a major contributor to the sand supply on the island's shelf.

The highest percentages of coral are found between depths of 5m and 15m (between 15 ft and 50 ft) across the entire reef (Figure 7). However, abundant coral is also found between depths of 20 m and 25 m (between 65 ft and 85 ft) in some localized areas.

Accuracy Assessment

Figure 8 shows the matrix of accuracy assessment calculations for the Major Biological Covers. A total of 816 points were checked in the field. The overall accuracy of 86.27% (with a 95% confidence interval of ± 2.36) indicates which points on the map were classified correctly according to the field check. A Tau coefficient of 0.9845 (with a 95% confidence interval of ± 0.85) indicates that 98% more points were classified correctly than would be expected by chance alone. The greatest amount of error was found in the Uncolonized class (Producer's Accuracy = 40.13%; User's Accuracy = 71.69%). In this instance, what we mapped as uncolonized sand on the fore reef at depths of approximately 27 m (90 ft) many times was found to be sand with >10% macroalgae (*Halimeda sp*.), which was too sparse to be resolved on the SHOALS data.

After accuracy assessment calculations were performed, any misinterpreted polygons on the South Moloka'i reef map(s) were corrected using the field check data, thus increasing the accuracy of the final map to greater than 86.27%.

Summary

The detailed high-resolution map layers provided here document habitat characterization of a critical coral reef in Hawai'i. Integration of the aerial imagery, SHOALS bathymetry, and field observations made it possible to create detailed thematic maps reaching depths of 35 m (120 ft). This depth range encompasses the base of the Moloka'i fore reef, and is deeper than can be mapped with standard optical remote sensing instruments. These maps can be used as stand-alone or in a GIS to provide useful information to scientists, managers and the general public.

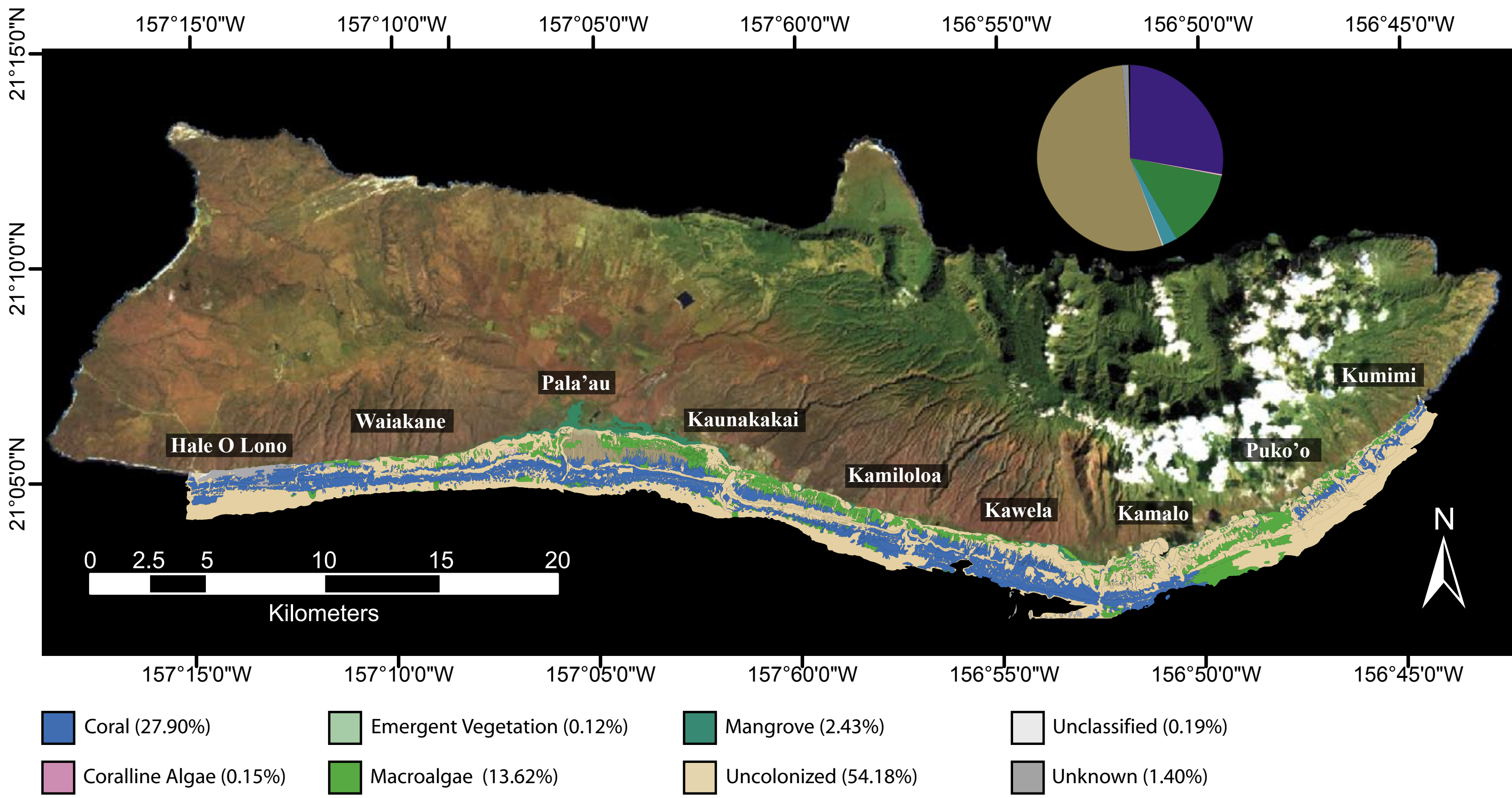

Figure 6. *Landsat satellite image overlaid with the benthic habitat classification map of Moloka'i showing the Major Biological Cover layer and the percentage of each class.*

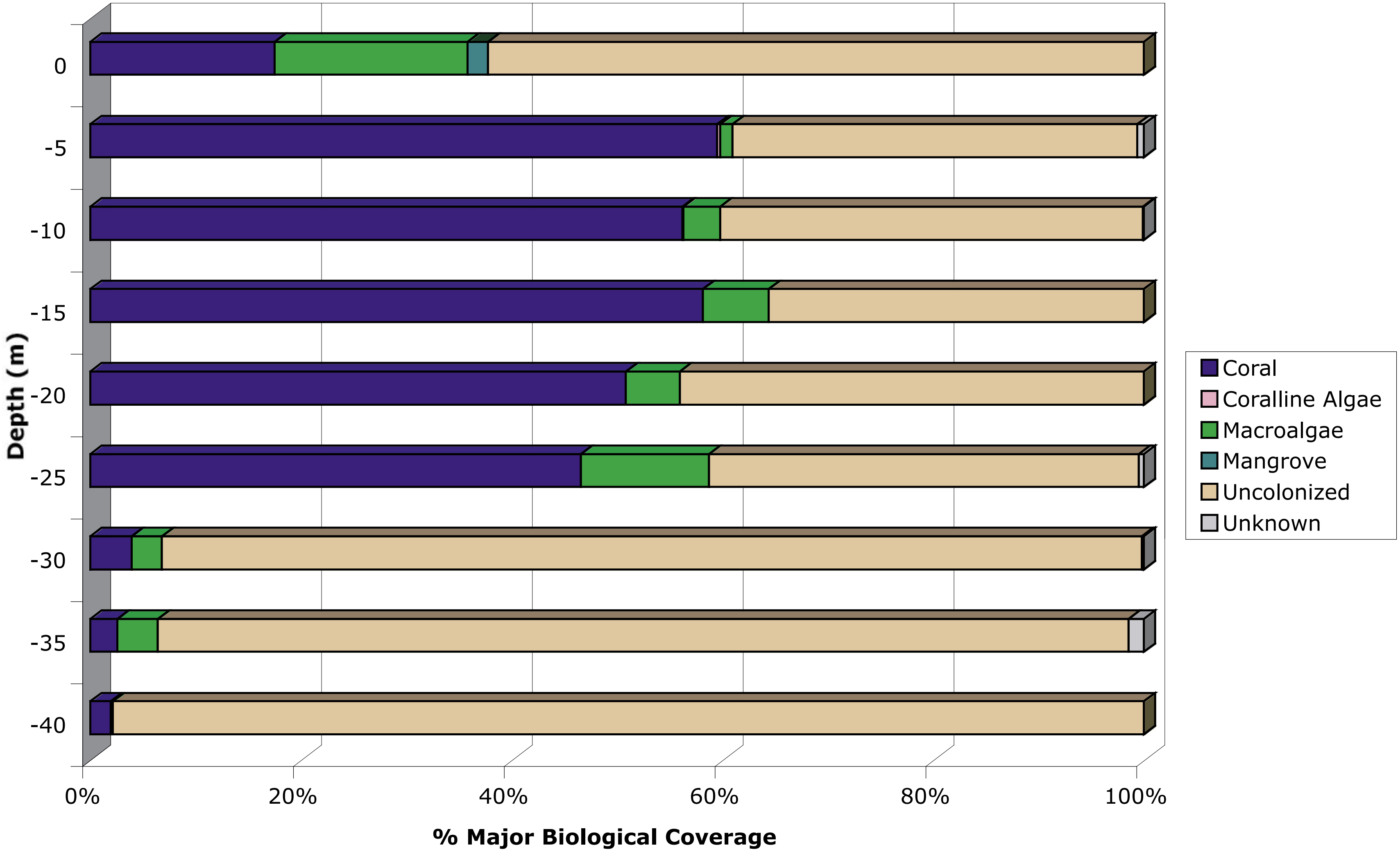

Figure 7. *Graph showing the variability of the percent Major Biological Cover with depth.*

As Mapped \ Found to be	1 Uncolonized	2 Macroalgae	3 Seagrass	4 Coralline Algae	5 Coral	6 Turf	7 Emergent Vegetation	8 Mangrove	Totals	User's % Accuracy
1 Uncolonized	233	85			7				325	**71.69%**
2 Macroalgae	4	61							65	**93.85%**
3 Seagrass									0	
4 Coralline Algae									0	
5 Coral	9	6		1	389				405	**96.05%**
6 Turf									0	
7 Emergent Vegetation							1		1	
8 Mangrove								20	20	**100.00%**
Totals	246	152	0	1	396	0	1	20	816	
Producer's % Accuracy	**94.72%**	**40.13%**			**98.23%**		**100.00%**	**100.00%**		**86.27%**

95% confidence level +/- 2.36

Figure 8. *Matrix showing the accuracy assessment calculations.*

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Additional Information

For an online version of this report, please see: http://pubs.usgs.gov/of/2005/1070/

To download the shapefile for use in a GIS, go to: http://pubs.usgs.gov/of/2005/1070/summary.html

For more information on the U.S. Geological Survey Western Region Coastal and Marine Geology Team, please see http://walrus.wr.usgs.gov/

For more information on the U.S. Geological Survey's Coral Reef Project, please see: http://coralreefs.wr.usgs.gov/

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